Transportation Infrastructure Precast Innovation Center (TRANS-IPIC)

University Transportation Center (UTC)

Continuous & Low-cost Inspection of Precast Concrete Bridges using Connected Automated Vehicles (CAVs)
UB-24-RP-01

Quarterly Progress Report
For the performance period ending 06/30/2025

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Collaborators / Partners:
None

Submitted to:
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TRANS-IPIC Quarterly Progress Report (Section 1 – 7, 5 pages max.):

Project Description:

1. Research Plan - Statement of Problem

   This project aims to develop a continuous, low-cost data collection system for bridges with precast components prone to reflective cracking. Early damage detection is crucial for durability, but existing inspection methods are costly, especially when performed continuously. Leveraging existing vehicles on the roads, we propose using vehicle-to-everything (V2X) technologies, where bridges request connected vehicles with standard forward-facing cameras to inspect critical areas. Connected automated vehicles (CAVs) will execute cooperative motion to maximize inspection efficiency. Aggregated data from continuous traffic and inspection results will detect early signs of damage, enabling proactive maintenance. To deliver such a system, a couple of problems need to be tackled: 1) how to design a robust crack-detection algorithm that can work with standard forward-facing cameras with limited focus on the road surface; 2) how to effectively communicate detection requests and results using CV2X communication; 3) how to coordinate the motion of the CAVs to maximize the detection results.

2. Research Plan - Summary of Project Activities (Tasks)

   This project has two main objectives with six sub-tasks.

   Objective 1: Develop a cooperative inspection system of road surface cracking between infrastructure and CAVs on the test track on the UB campus.

   - Task 1.1: Develop a vision-based road cracking inspection algorithm using a vehicle forward-facing camera.
   - Task 1.2: Update the V2X protocol to enable information sharing between vehicles and infrastructure
   - Task 1.3: Design cooperative vehicle motion planning control algorithms with V2X information to maximize crack inspection efficiency

   Objective 2: Implement and demonstrate the developed cooperative inspection system on a precast concrete bridge in NYS

   - Task 2.1: Identify ideal precast concrete bridge sites in NYS near the UB Campus
   - Task 2.2: Deploy and fine-tune the cooperative inspection system at the identified sites
   - Task 2.3: Deliver a demonstration of the developed system at a pilot site

Project Progress:

3. Progress for each research task

   Objective 1 [70% completed]:

   Task 1.1 [60%] This quarter, the research team continued developing vision-based road cracking inspection algorithms. While progress is made, the team is also encouraged to take on more challenges and actively tackle them.

   Specifically, the team refined the structure of the model developed in the previous quarter (based on [1] [2]). We obtained models with metrics close to those reported in the original paper. See Figure 1 where the higher the number, the better the performance.

Model	Dataset	ODS	OIS	AP
LECSFormer Results [1]	CrackTree260	0.9630	0.9690	0.9690
Retrained results		0.9472	0.9525	0.9446
LECSFormer Results [1]	CrackLS315	0.9170	0.9270	0.9150
Retrained results		0.8919	0.8391	0.8830
LECSFormer Results [1]	Stone331	0.9520	0.9700	0.9600
Retrained results		0.9217	0.8852	0.9253

Figure 1 Crack detection model performance on public data set

The team is now working on model-based algorithms that relate crack detection results at the pixel level to an estimation of crack size.

While the model's performance is satisfactory, it exhibits some degradation in zero-shot performance, i.e., when applied to the real images acquired from the vehicle's forward-facing camera. As illustrated in Figure 2 The model can falsely identify many non-structural cracks due to weather conditions, such as shade and window glare. This could also be due to the insufficient open-source dataset on which the model is trained. Furthermore, due to the low resolution of the camera, current preliminary testing is being done offline, with the area of interest picked manually.

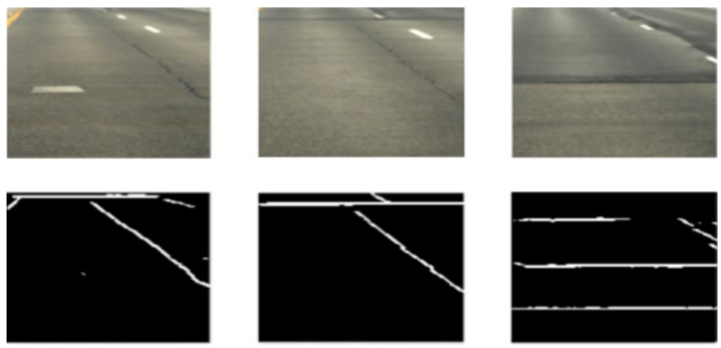


Figure 2 Crack detection performance with vehicle forward-facing camera

To address these challenges and achieve real-time detection, the team is actively exploring the following solutions, considering the project's scope.

1) Apply anti-glare or reflection removal to images that mitigate weather-related conditions. The filtered image will mitigate non-crack details that trigger false positives.
2) Developing algorithms that determine a cropping window that contains the relevant crack based on the area of interest requested by the infrastructure. The team has proposed a preprocessing scheme to correlate the area of interest for detection with the camera's field of view. Such a scheme will provide the crack detection algorithm with the image snippet that contains the crack of interest with the best resolution.
3) Generating an additional dataset based on the vehicle camera view of the surface crack near the UB campus and adding it to the training dataset. This will allow fine-tuning of the detection model to the target application of this project.

Task 1.2 [80% completed] This quarter, the research team has finished quantifying the bandwidth available from the C-V2X SAE J2735 standard and customized messages. The team is using customized messages and actively developing the communication protocol for detection results between the vehicle and infrastructure. The current proposed communication protocol is shown in Figure 3.

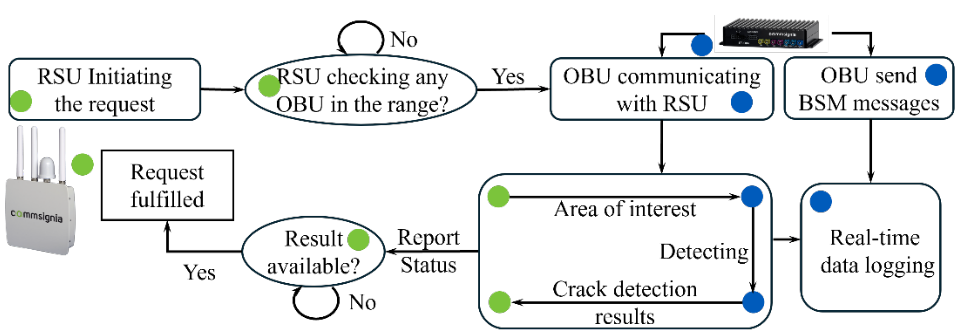


Figure 3 Crack detection application communication protocol

This protocol has been implemented and evaluated. Preliminary results, e.g. those shown in Figure 4, indicate that one set of detection results, ~200 kilobytes (kB) in size, can be transmitted within 3 seconds. This meets the original task requirements. A preliminary demonstration with the above communication protocol can be found here. In the video, the image snippets with detection results were successfully acquired by the roadside unit (RSU).

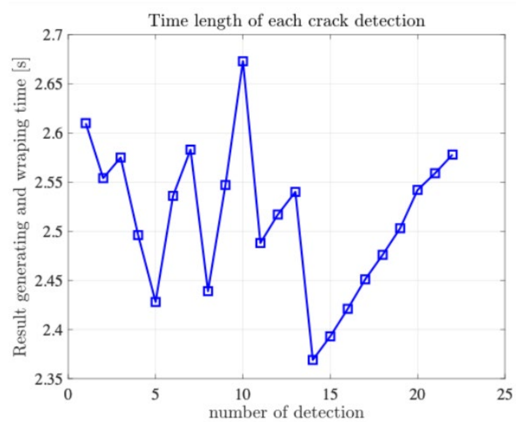


Figure 4 Detection results transmission time

The team identified issues and further challenges related to the communications pipeline, e.g., interruptions caused by package losses. In the next quarter, the team will continue to optimize the protocol and conduct robust analysis. The team will work closely with CV2X vendor Commsignia and extend protocols to accommodate interruptions, allowing results to resume and/or retransmission after package loss.

Task 1.3 [80% completed] This quarter, the research team has also started implementing the CV2X-based vehicle motion control on the Lincoln connected automated vehicle (CAV) Platform at UB [3, 4]. The team successfully implemented and tested longitudinal control algorithms on CAVs, enabling them to regulate their speed according to the infrastructure's requested set speed while maintaining safety in traffic. The time profiles corresponding to an example run are illustrated in Figure 5. As shown in the figure, the CAV (blue) can follow the same speed suggested by the vehicle ahead (red) while staying a safe distance (Headway). A demonstration video can be found here. Part of the longitudinal control is included in the accepted paper [4].

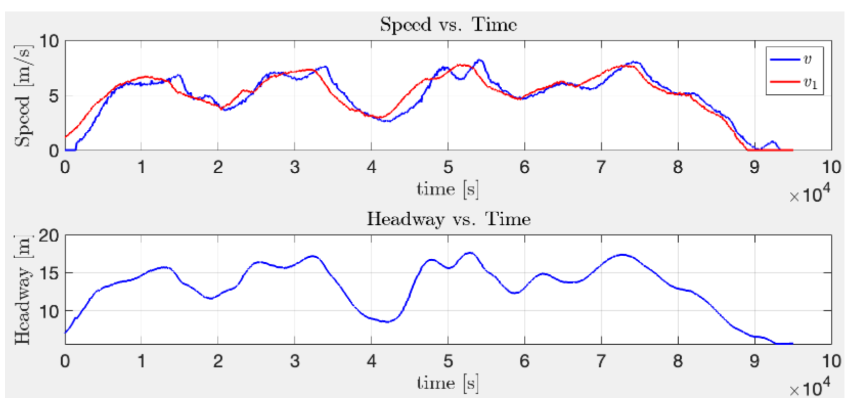


Figure 5 CV2X-based motion control performance: longitudinal speed tracking

The team is on track to implement speed control as part of the crack detection algorithm. Specifically, in coordination with the cropping window algorithm design mentioned in Task 1.1, vehicle longitudinal speed will be optimized in the next quarter to enhance crack detection performance.

Objective 2 [30% completed]
Task 2.1 [100% completed]
With the help of the NYS DOT team. We have identified one precast bridge candidate (Bridge Bin# 1045890, Google Map) near the UB campus; see Figure 6. We have obtained historical inspection results and started planning the demo and evaluation metrics.

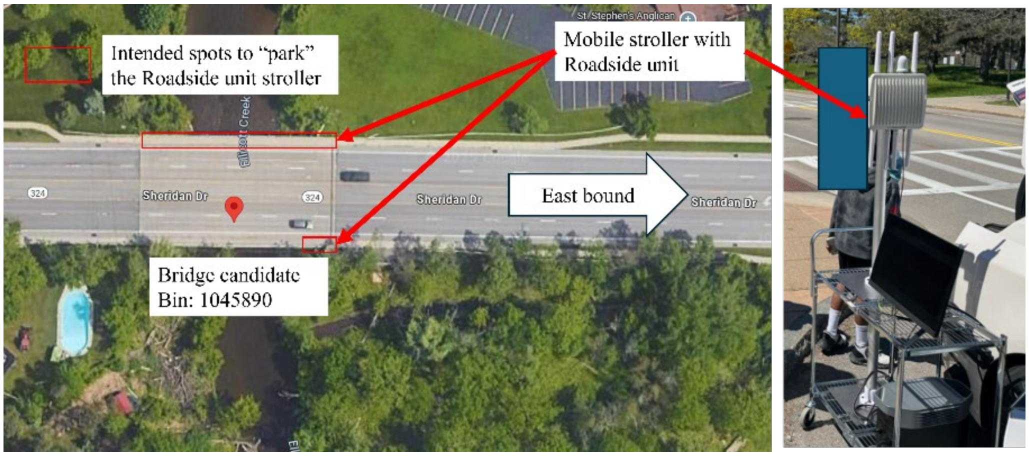


Figure 6 Identified bridge candidate and demo setup

Task 2.2 [10% completed]

Once the bridge was identified, the team paid a few site visits to collect image data and to plan for deployment and fine-tune activities. A bridge site similar to the pilot site in geometry and configuration is identified at UB; see Figure 7. This is to facilitate deployment and fine-tune the algorithm development related to Task 1.1. The fine-tuning process has primarily taken place at this bridge site. In the next quarter, the process will be conducted at both sites and will eventually be shifted to the pilot site.

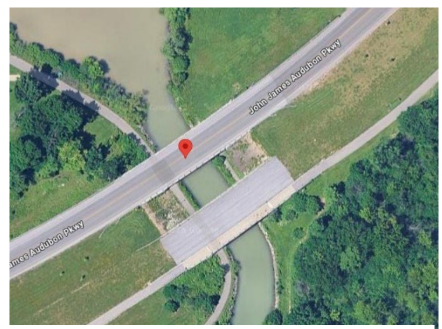


Figure 7 New identified test site on UB campus (Google map)

We remark that this new site will facilitate more efficient development and fine-tune activities, complementing those at the identified pilot site. Thus, it is categorized under Task2.2 and it would not impact on the original timeline.

Task 2.3 [0% completed] (Not started)

4. Percent of research projects completed

More technical challenges were encountered, primarily in Task 1.1; thus, we estimated that 50% of the total project will be completed at the end of this quarter. Progress is also impacted by unplanned technical issues and maintenance related to the connected automated vehicle platform. The team is expected to catch up in the next quarter.

5. Expected progress for next quarter

The research team will seek to achieve Objective 1 and start moving towards achieving Objective 2. Specifically, for Objective 1, the team will collect additional data, refine and finalize the model design, and continue to optimize the inference pipeline (Task 1.1). We will also finalize it in conjunction with CV2X message customization that supports the transmission of detection results (Task 1.2). We also seek to finalize the vehicle control implementation (Task 1.3). For Objective 2, the team will begin fine-tuning and validation at the identified pilot site (Task 2.2) and plan for the final demonstration.

6. Educational outreach and workforce development

The funding supported and trained one Ph.D. student, Haosong Xiao, and two master's students, Harsh Bhargava and Rishabh Shukla, on connected automated technologies and infrastructure maintenance/inspection protocols.

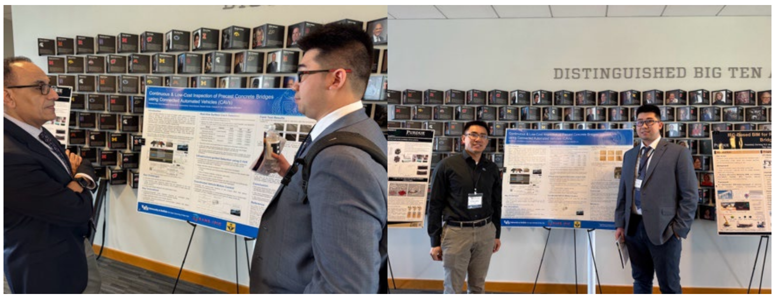
The research team actively participated in all TRANS-IPIC Monthly Webinars.

7. Technology Transfer
   None

Research Contribution:

8. Papers that include TRANS-IPIC UTC in the acknowledgments section:
   None

9. Presentations and Posters of TRANS-IPIC funded research:
   The research team presented a poster on the preliminary findings at the TRANS-IPIC workshop on April 22-23, 2025.



10. Please list any other events or activities that highlight the work of TRANS-IPIC occurring at your university (please include any pictures or figures you may have). Similarly, please list any references to TRANS-IPIC in the news or interviews from your research.

    PI Chaozhe He and his team participated in the UB Robotics Day on April 27, 2025, and showcased the project's outcome to K-12 students.

PI Chaozhe He gave a lightning talk, "*Towards resilient infrastructure with connected automated vehicles*", highlighting the research activities of this project, at the 2025 Joint UB SEAS Workshop on AI, Personalized Health, and Clean Energy, on May 12th, 2025.

Appendix 1: Research Activities, leadership, and awards (cumulative, since the start of the project)

A. Number of peer-reviewed publications accepted based on outcomes of UTC funded projects
   - No. = 1
     H. Xiao and C. R. He. "*Safe and Efficient Connected Cruise Control*." 4th Modeling, Estimation, and Control Conference (MECC 2025), Pittsburgh, PA, October 2025.

B. Number of transportation-related classes developed or modified as a result of TRANS-IPIC funding.

- No. Graduate = 1: MAE 502 Vehicle Control Systems (Spring 2025).

References:

[1] Liu, Y., et al. "DeepCrack: A deep hierarchical feature learning architecture for crack segmentation," in Neurocomputing, vol. 338, pp. 139–153, 2019, doi: 10.1016/j.neucom.2019.01.036

[2] J. Chen, N. Zhao, R. Zhang, L. Chen, K. Huang and Z. Qiu, "Refined Crack Detection via LECSFormer for Autonomous Road Inspection Vehicles," in IEEE Transactions on Intelligent Vehicles, vol. 8, no. 3, pp. 2049-2061, March 2023, doi: 10.1109/TIV.2022.3204583.

[3] S. Beregi, S. S. Avedisov, C. R. He, D. Takács, and G. Orosz. Connectivity-based delay-tolerant control of automated vehicles: theory and experiments. IEEE Transactions on Intelligent Vehicles, 8(1): 275-289, 2023

[4] H. Xiao and C. R. He. "*Safe and Efficient Connected Cruise Control*." 4th Modeling, Estimation, and Control Conference (MECC 2025), Pittsburgh, PA, October 2025.